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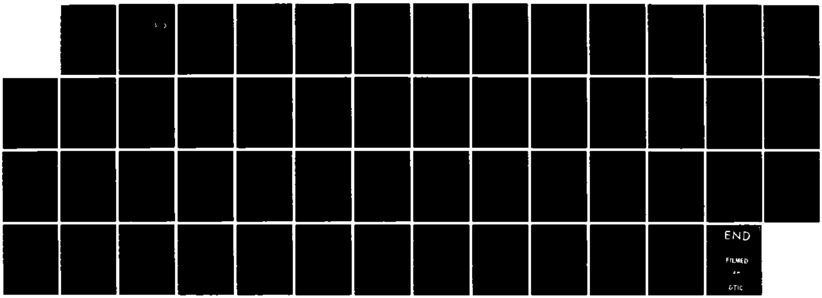

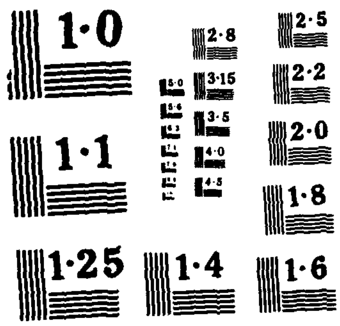

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APPENDIX 4.

Wright, L. D., Short, A. D., Boon, J. D., Hayden, B., Kimball, S. and List, J. H., in press. Morphodynamic responses of an energetic beach to temporal variations in wave steepness, tide range, and incident wave groupiness, submitted to Mar. Geol. (48 pp.).

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The empirical analyses of short-term beach and surf zone morphodynamic response to changing breaker conditions by Wright et al. (1985a) are extended to examine the additional roles played by daily tide range and incident wave groupiness. Complex demodulation of original tide and wave time series from the moderate energy Narrabeen Beach, Australia, resulted in new time series of daily tide range and a daily grouping factor which expresses the relative amplitude of the alternation between groups of high

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Both tide range and groupiness are significant determinants of beach state. The six beach states are: reflective, low-tide terrace, transverse bar and rip, rhythmic bar and beach, longshore bar trough, and dissipative (Wright and Short, 1984). Provided that Ω is within the appropriate range to favor beach states at the reflective end of the sequence, spring tides will tend to favor either the low-tide terrace or reflective states over the transverse bar and rip state. The transverse bar and rip state is best developed during neap tides. Higher tide ranges are also associated with more subdued bar-trough topography; the more accentuated bar-trough profiles are developed when tide range is minimal. Overall, higher relative incident wave groupiness favors the more dissipative states. Incident wave groupiness is the dominant factor determining whether the low-tide terrace state or transverse bar and rip state prevails, provided Ω is such as to permit one or the other of these states. Groupiness is also important in discriminating between the transverse bar and rip and rhythmic bar and beach states.

MORPHODYNAMIC RESPONSES OF AN ENERGETIC BEACH TO TEMPORAL VARIATIONS IN WAVE STEEPNESS, TIDE RANGE, AND INCIDENT WAVE GROUPINESS

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Abstract

The empirical analyses of short-term beach and surf zone morphodynamic response to changing breaker conditions by Wright et al. (1985a) are extended to examine the additional roles played by daily tide range and incident wave groupiness. Complex demodulation of original tide and wave time series from the moderate energy Narrabeen Beach, Australia, resulted in new time series of daily tide range and a daily grouping factor which expresses the relative amplitude of the alternation between groups of high and low waves. Using these new time series together with time series of daily beach state and of the parameter $\Omega = H_b/(w_s T)$ (H_b=breaker height; w_s=sediment fall velocity; T=wave period), statistical analyses were performed aimed at determining the contributions made by each factor in explaining time-varying beach state. Eigenvector analyses of monthly surveyed beach and surf zone profiles provided a set of time series on modes of profile configuration change which were also analyzed to determine the relative effects of Ω and tide range on profile shape.

Both tide range and groupiness are significant determinants of beach state. The six beach states are reflective, low-tide terrace, transverse bar and rip, rhythmic bar and beach, longshore bar trough, and dissipative (Wright and Short, 1984). Provided that Ω is within the appropriate range to favor beach states at the reflective end of the sequence, spring tides will tend to favor either the low-tide terrace or reflective states over the transverse bar and rip state. The transverse bar and rip state is best developed during neap tides. Higher tide ranges are also associated with more subdued bar-trough topography; the more accentuated bar-trough profiles are developed when tide range is minimal. Overall, higher relative incident

wave groupiness favors the more dissipative states. Incident wave groupiness is the dominant factor determining whether the low-tide terrace state or transverse bar and rip state prevails, provided Ω is such as to permit one or the other of these states. Groupiness is also important in discriminating between the transverse bar and rip and rhythmic bar and beach states.

Introduction

Recently, Wright et al. (1985a) concluded from analyses of a 6.5 year time series of quasi-daily observations of offshore waves and beach and surf zone states, on an exposed high energy beach, that time-varying beach state can be partially predicted in terms of the parameter

$$\Omega = H_b/(w_s T) \qquad (1)$$

where H_b is breaker height, T is peak breaker period, and w_s is the mean fall velocity of the beach sand. A weighted mean value of Ω, computed from daily values for the several days preceding the day for which prediction is sought, was found to be the best predictor. Beach state, in this context, refers to the six morphodynamic states which have been discussed in detail by Wright and Short (1984) and Wright et al. (1985a). Briefly, these states include the dissipative (flat beach, high breakers) and reflective (steep beach, low breakers) extremes and 4 intermediate states which, in order of decreasing surf energy, are: longshore bar-trough; rhythmic bar and beach; transverse bar and rip; and ridge-and-runnel/low tide terrace. Encouraging results were obtained in the earlier study (Wright et al., 1985a) suggesting that beach state could be roughly predicted with an overall success rate of 68% in terms of a weighted mean value of Ω provided that beach states were

regrouped into only three broad classes ([1] Reflective or low tide terrace; [2] transverse bar and rip or rhythmic bar-and-beach; [3] longshore bar trough or dissipative). In addition, Wright et al. (1985a) concluded that the direction (but not the rate) of beach state change could be predicted in terms of Ω and antecedent beach state. However, a considerable fraction of the temporal variability in beach state could not be predicted or explained. Furthermore, the parameters used by Wright et al. (1985a) proved to be poor discriminators between proximal beach states (e.g. for predicting whether the beach state is likely to be "longshore-bar-trough" or "rhythmic-bar-and-beach").

In addition to the time series of daily beach state observations, monthly surveys of the beach and surf zone profiles were made of the same beach spanning the same 6.5 year period. The results of a preliminary examination of the modes of profile behavior, their temporal variability, and their relationships to beach state were reported by Wright et al. (1985b). Different profile response components were separated by means of empirical eigenvector analyses. The lower order modes of profile variability, expressing beach volume and overall surf zone gradient vary slowly and apparently, independently of shorter term variations in Ω; these modes were inferred to be the result of slow (> 1 yr) cross-shore exchanges of sediment between the surf zone and the inner shelf (Wright et al., 1985b). Higher, faster response, modes related to more subtle profile features, such as bar-trough shapes and asymmetries, showed a stronger association with beach state and with Ω; again, however, a considerable fraction of the variability remained unexplained.

Inasmuch as the analyses reported by Wright et al. (1985a & b) relied solely on Ω as the first-order predictor, it is not surprising that only partial success was achieved in predicting short-term beach behavior. Wright et al. (1985a) pointed out that additional and potentially important roles should be played by temporal variations in tide range (for example, the neap to spring variation among others) and in the groupiness of the incident waves (that is, the degree to which packets or sets of higher waves alternate with lower waves). These factors, together with Ω are hypothesized to determine short term changes in beach state and profile configuration. However, since both beach state and profile changes must be considered against the background of very slow alternations in the volume of inshore sand storage (Wright et al., 1985b), only partial predictability may be expected even when the effects of the additional variables are considered.

The purpose of this paper is to evaluate the relative degrees to which time-varying Ω, tide range, and incident wave groupiness act to determine beach state and associated beach profile configuration. The results we report are derived from empirical/statistical analyses of a long time series of data from a single, dynamic, beach. We do not offer a universal scheme for predicting the detailed behavior of beaches and surf zones.

The Data Set and Methods of Analysis

-- Field observations --

The data on which this paper is based were obtained from the moderate to high energy coast of Southeastern Australia. This is the same data set that has been described most recently by Wright and Short (1984) and Wright et al. (1985a & b). Beach state was recorded daily at 8 locations on

Narrabeen Beach near Sydney, N.S.W.; beach and surf zone profiles were surveyed monthly at the same locations. The time series of daily beach state and monthly profiles reported here is 6.5 years long. Daily wave data covering the same period were obtained from the Sydney offshore wave rider which is maintained by the Maritime Services Board of New South Wales. The beach is composed of medium-sized quartz and carbonate sand. It experiences semidiurnal tides with a mean spring tide range of 1.6 m and a mean neap tide range of 1.2 m. Breaker heights exhibit considerable temporal variability producing rapid changes in beach states. Long period (T = 8-14 s) swell maintain a moderate energy background throughout all seasons. Highly variable wind waves, related principally to mid-latitude cyclones, are superimposed.

-- Analysis of beach and surf zone morphology --

The daily beach state observations provided a time series which required no further manipulation prior to statistical determinations of the associations between beach state and potential forcings. The data set from the monthly levelling transects of beach and surf zone profiles was subjected to considerable further reduction prior to attempting to establish causal relationships. Specifically, different, approximately independent, modes of profile behavior were separated by means of principal components analyses. In these analyses empirical eigenvectors were calculated at the University of Virginia from the correlation matrix following the method of Kutzbach (1967) and Vincent et al. (1976) and as used by Hayden et al. (1979). The time-varying weightings (expressing, typically, vertical upward or downward shifts of different points on the profile around the mean) as obtained for each eigenvector provided a new set of time series which were

used in subsequent analyses of profile change. Weightings on the dominant eigenvectors were previously subjected to spectral analyses to determine the dominant frequencies of variation of the different vectors (Wright et al., 1985b). Two types of eigenvectors were computed: (1) "fixed datum" analyses in which the profiles were related to a fixed datum (e.g. a benchmark) and the resulting modes of variability primarily express changes in patterns of volumetric sediment storage; and (2) "floating datum" analyses in which the datum is simply the instantaneous shore-line position and from which are derived modes of variability expressing profile shape independent of absolute beach volume. The floating datum modes of profile behavior proved to be the most meaningful in terms of expressing changing surf zone morphodynamics and are the primary modes dealt with here.

-- Estimation of Ω --

For the purposes of the analyses reported in this paper, Ω and a weighted mean value, Ω were computed as in Wright et al. (1985a). The significant breaker height (after refraction, shoaling and frictional dissipation effects were taken into account) and peak period as obtained from wave rider statistics were used as the H_b and T values in Equation 1. The settling velocity w_s of the Narrabeen Beach sand typically ranges from 0.045 m s^{-1} to 0.066 m s^{-1} depending on location. The effects of this shore-normal variation in settling were taken into account to some degree by using different w_s values depending on the width of the surf zone. Variations in w_s due to seasonal differences in seawater temperature were not considered but may be significant.

The beach configuration as observed at any given time is more often the product of recently antecedent processes than it is of the processes

prevailing at the time of observation. Hence, a weighted mean value, $\bar{\bar{\Omega}}$, taking account of conditions several days prior to observations was computed from

$$\bar{\bar{\Omega}} = \left[\sum_{j=1}^{D} 10^{-j/\phi} \right]^{-1} \sum_{j=1}^{D} (\Omega_j \; 10^{-j/\phi}) \tag{2}$$

where j = 1 on the day just preceding the beach state or profile observations and j = D on D days prior to observation. The parameter ϕ depends on the rate of memory decay. At ϕ days prior to observation, the weighting factor has decreased to 10%. Wright et al. (1985a) found that the highest degree of explanation for the dynamic Narrabeen Beach was achieved with ϕ = 5 days and D = 30 days so those values are used here.

-- Quantification of temporal variability of wave groupiness --

We reviewed the existing techniques for quantifying the degree of wave groupiness, including those used by Goda (1970), Funke and Mansard (1979), and Thompson (1982). The method proposed by Funke and Mansard (1979) was based on a smoothed instantaneous wave energy history, which is merely a squared and then low-passed filtered incident wave time series. However, due to the non-linear computations required in the calculation, the groupiness factor thus defined does not have well-defined upper and lower limits. This makes the intercomparison of the groupiness factors among different time series difficult to interpret. We define an improved groupiness factor GF in terms of a wave envelope or groupiness time series g_t,

$$GF = \frac{\sqrt{2} \; \sigma_g}{\bar{g}_t} \tag{3}$$

(σ_g = standard deviation of g_t, $\bar{g}_t$ = mean of g_t). The groupiness series g_t was obtained by low pass filtering the absolute value of the wind wave band sea surface time-series and scaling the result with a factor of $\pi/4$. This simple method of complex demodulation produces a visually excellent envelope function that closely follows 1/2 the wave amplitude. The groupiness factor GF given here thus represents a measure of wave amplitude variability and has a well-defined upper limit of 1 for perfectly grouped waves and a lower limit of 0 for waves with constant wave amplitude. Figure 1 illustrates the g_t and groupiness factor correspondence to different wave time-series.

In order to relate wave groupiness to daily beach state and monthly beach profile data, it was necessary to obtain daily time series of unprocessed offshore wave data from the Sydney Region (near Narrabeen Beach from which the data come) encompassing times during which beach observations were made. We obtained from the N.S.W. Maritime Services Board a data set covering 613 days of 1977 and 1978 (the period over which our data set has the fewest interruptions). For each day covered by the data there are on average 3 time series per day giving us a total over 1,800 time series. Each time series is about 18 minutes long; the sampling interval (Δt) was 0.5 sec. We analysed each series for groupiness and found daily averages to obtain a 613 day groupiness time series. As in the calculation of $\bar{\bar{\Omega}}$, $\overline{\overline{GF}}$ was weighted using equation 2 to account for antecedent conditons.

-- Temporal variations in tide range --

Long period variations in the tide include periodic components having semimonthly, monthly, semiannual and annual periods. The tidal constituents used to represent these temporal variations in water level are well known and may be extracted from records of the observed tide using simple

filtering methods and harmonic analysis. The linear combination of these constituents yields the familiar seasonal tide curve which, on a given day, suggests little more than a linear trend in water level rise or fall and shows the local sea level stand in relation to yearly mean sea level. What is not shown in a seasonal tide curve is the contribution made by tidal range to sea level variance at time scales longer than those of the major semidiurnal and diurnal tidal components (i.e. M2, S2, N2, K1 and O1). Usually we see this variation in daily (hourly) tide curves as a beat frequency or a modulation on what we may regard as the carrier wave of the tidal signal, the M2 tide, as it interacts with the other constituents of lesser amplitude but similar frequency.

We used 37 tidal constituents to compute tidal range (TR) and mean (daily) sea level time series embracing the same period as our daily beach state and Ω data. We employed the same method of complex demodulation used in computing the groupiness time series except that longer filter cutoffs are used in the case of the tides and amplitudes are a factor of 2 larger than for the groupiness envelope function. Multiplying all of the new values by π , the series is made to contain the same mean range value as the original series. Using a low pass filter with a cutoff period of approximately 72 hours (we use a least squares digital filter with a filter width of 24 hours), the final series emerges that shows the tidal range as a function of time. Figure 2 shows a one-year time series of time varying tide range and associated mean sea level as computed by this method from the tidal constituents for Sydney. In order to allow for the potential importance of antecedent conditions, weighted mean values of daily tide

range, $\bar{\bar{TR}}$, were estimated using the same technique as was used in estimating $\bar{\bar{\Omega}}$ (eq. 2). These values are also shown in Figure 2 (by the crosses).

-- Methods of determining statistical associations --

We produced long, simultaneous time series of beach state, Ω, $\bar{\bar{\Omega}}$, the grouping factor, GF, and tide range, TR, as shown in Figure 3. Additionally, we produced time series of the weightings on the various eigenvectors used in characterizing profile behavior. These data were used in statistical analyses aimed at estimating the degree of association between the various forcing functions and beach and surf zone morphologic responses. Discrete discriminant analysis (Nie et al., 1975; Goldstein and Dillon, 1978) similar to the technique used by Wright et al. (1985a) was used to determine the degree to which the forcing functions ($\bar{\bar{\Omega}}$, $\bar{\bar{GF}}$, $\bar{\bar{TR}}$) in different combinations are responsible for different discrete beach states. This type of analysis also permitted the relative roles played by the different forcing functions to be assessed and was used in determining the factors responsible for positive versus negative change in the weightings on different eigenvectors. In addition, conventional correlation and regression analyses were used, largely as an exploratory tool, in an attempt to determine relationships between modes of profile change and forcings.

Sources of Beach and Surf-zone Morphodynammic Change: Rationale

-- Role of Ω and comparable parameters --

There is nothing original about our hypothesis that beach behavior depends, to a significant degree, on sediment size, wave height, and wave period. There is an immense body of literature reporting the results of both laboratory and field studies which show that beaches flatten with decreasing grain size and increasing wave steepness and steepen with

increasing grain size and decreasing wave steepness. Sunamura (1984) has recently synthesized and reanalyzed the data from many of those studies. Sunamura (1984), using 24 laboratory data sets and 12 field data sets, derived empirical expressions for predicting beach slope, $\tan \beta$, as a function of the ratio $H_b/(g^{1/2}d^{1/2}T)$ where H_b is breaker height, g is the acceleration of gravity, d is the grain size of the beach sediment and T is wave period. Although Sunamura's curves show good agreement with data for cases of low $H_b/(g^{1/2}d^{1/2}T)$ values and steep, highly reflective ($\tan \beta>0.1$) beaches, the curve is nearly horizontal and the scatter spans a full order of magnitude for the more common natural situations where $0.1>\tan \beta>0.01$.

If one assumes uniform sediment density and particle shape, variations in the parameter Ω which we use are directly parallel to variations in Sunamura's (1984) parameter. The parameter Ω was originally suggested by Dean (1973) and subsequently used by Dalrymple and Thompson (1977) in analyses of equilibrium beach profiles. We prefer Ω to parameters like that of Sunamura (1984) or comparable alternatives (some of which are described by Hallermeir, 1985) because it necessitates no simplistic assumptions as to the constancy of particle shape or density. Furthermore, Ω is a physically understandable quantity: H_b indexes the maximum potential distance that a sediment particle might be lifted above the bed whereas $w_s T$ is the maximum potential distance that a particle can fall in one wave cycle. Although beach slope and beach state are not equivalent, dissipative beaches are flat and reflective beaches are steep. Hence one would expect an association between Ω and beach state. Wright and Short (1984) found a good association between the modal values of Ω and modal beach state for different beaches.

Wright et al. (1985a) showed that much of the temporal variability of a single beach could be explained in terms of $\bar{\bar{\Omega}}$.

-- Groupiness of incident waves --

Estimates of Ω are based on a single statistically-determined value of H_b, specifically the significant wave height. Use of a single H_b value is strictly only appropriate if wave height is uniform which it is not in nature. The degree of groupiness of the incident waves may be expected to affect significantly the total amount of work performed in the surf zone. For example, since the rate at which the waves perform work on the bed is proportional to the cube of the wave height, a groupy incident wave regime having any specified (statisical) H_b value will perform more work than a regime of uniform waves having the same H_b statistic.

Secondly, there exists field evidence suggesting the possible influence on nearshore infragravity waves by the low frequency fluctuations associated with groupy wave trains. As was shown by Longuet-Higgins and Stewart (1964), amplitude modulation of a groupy wave train forces a long wave through its spatial (and temporal) variation of the radiation stress. The surf beat phenomena observed by Munk (1949) and Tucker (1950) were interpreted by Longuet-Higgins and Stewart (1964) to be related to the reflected forced long waves. Field observations by Fujinawa (1979) and Sand (1982) also indicated the presence of the forced long waves offshore of the surf zone. Furthermore, as the waves of the wave group break at different locations in the surf zone, a low frequency oscillation may be created which may also contribute to the infragravity energy in the surf zone (Symonds, et al.1982). It is now recognized widely that infragravity waves play important roles in the dynamic processes of the surf zone.

The third possible effect of the groupy wave train on nearshore processes is related to the on/off shore exchange of sediment. It was pointed out in Wright et al. (1985b) that shore-normal sediment exchange in the nearshore zone involves two processes; a short-term process controlling sediment exchange inside the surf zone and a long-term process controlling sediment exchange between the surf zone and the inner shelf. Although detailed mechanisms controlling these on/off shore sediment transport processes have yet to be investigated, Shi and Larsen (1984) have suggested a possible seaward sediment-transporting mechanism by groupy wave trains. Since the forced long waves of a wave group produces a second order mean current flowing in the direction opposite to that of the wave propagation beneath the higher waves of the wave group, the coupling between the mean seaward flow and the higher waves of the wave group is capable of producing net seaward sand transport. This seaward transport mechanism by the grouped wave train may constitute one of the mechanisms determining the long term sediment exchange processes on the inner shelf.

-- Temporal variations in tidal range --

Wright et al. (1982) concluded from a study of a macrotidal beach that the constantly changing surf zone conditions that are produced by a large tidal range inhibit the development of resonant phenomena such as edge waves and rhythmic beach and surf zone features. In contrast to the macrotidal case, Wright et al. (1986) note that accentuated bar-trough morphology such as is associated with the "longshore-bar-trough" and "rhythmic-bar-and-beach" states is favored by small tidal ranges. Narrabeen Beach experiences only a moderate tidal range but with significant neap to spring variation. Since the time frame of the alternation between neap and spring tides is on

the same order as the typical response time for the beach to change state (order 1 week- Wright et al. (1985 a & b) we hypothesized that beach state and beach profile configuration should depend in part on time varying tidal range.

-- Additional Factors --

Beach behavior is likely to be significantly affected by several factors which have not been included in our analyses. Most important among these is probably the slow cycling of sand between the inner shelf and the inshore zone for reasons which remain poorly understood (e.g. Wright et al. 1985b). Seasonal variations in seawater temperature and hence in w_s may also be important. Variations in the details of incident wave spectra are certain to be important but have not been included in the analyses. Intuitively, one would expect variations in the intensity and direction of alongshore thrust S_{xy} (and hence in littoral drift) to be of paramount importance as it is on straight, unbounded beaches. Owing to the embayed, headland-bounded configuration of the Narrabeen compartment, and the degree to which refraction maintains approximately shore-normal breaker angles, littoral drift, and temporal variations thereof, are negligible.

Sources of Beach State Variability: Statistical Results

-- Results of "six-state" analyses --

Wright et al. (1985a) performed discriminant analyses aimed at ascertaining the degree to which the six beach states can be distinguished- and predicted-in terms of immediate and antecedent values of Ω. The results were unimpressive: the overall predictability sucess rate was only 23.4%. In the present study, we attempted to improve predictability by introducing two additional variables, weighted mean tide range, $\bar{\bar{TR}}$, and weighted mean

grouping factor, $\overline{\overline{GF}}$, into the same type of analyses as used by Wright et al. (1985a). Our time series of $\overline{\overline{GF}}$ spans a total period of only 613 days embracing only 586 beach state observations whereas our time series of $\overline{\overline{\Omega}}$ and $\overline{\overline{TR}}$ cover a period of 6.5 years during which 1842 cases are represented. We therefore conducted two sets of analyses: one set covering 586 cases and utilizing Ω, $\overline{\overline{TR}}$, and $\overline{\overline{GF}}$ and another set covering 1842 cases but excluding $\overline{\overline{GF}}$.

Figure 4 and Table 1a indicate the central tendencies of the $\overline{\overline{\Omega}}$, $\overline{\overline{TR}}$, and $\overline{\overline{GF}}$ values corresponding to each of the six beach states. From Figure 4 it is apparent that, overall, the greatest separation between beach states is in terms of $\overline{\overline{\Omega}}$ and, secondarily, in terms of $\overline{\overline{GF}}$. Differences in $\overline{\overline{TR}}$ between different states are small; however, it must be remembered that temporal variations in tidal range are small to begin with. The F-ratios and significance levels presented in Table 1b confirm what is visually obvious from Figure 4 and Table 1a: the means of $\overline{\overline{\Omega}}$ and $\overline{\overline{GF}}$ differ significantly between states whereas the means of $\overline{\overline{TR}}$ do not.

The results of a discriminant analysis aimed at discriminating between the six beach states in terms of $\overline{\overline{\Omega}}$, $\overline{\overline{TR}}$, and $\overline{\overline{GF}}$ are presented in Tables 2a,b,c and Table 3. From Table 2a, three discriminant functions are identified. Function 1 is by far the most important of the three and expresses nearly 93% of the total variance, as indicated by the standardized canonical discriminant function coefficents. $\overline{\overline{\Omega}}$ makes the dominant contribution to this function with $\overline{\overline{GF}}$ making a secondary but important contribution. The role of $\overline{\overline{TR}}$ in contributing to the discriminating power of function 1 is negligible; however $\overline{\overline{TR}}$ is very important to functions 2 and 3. The general substance of the results is that they suggest, with a high

degree of statistical significance, that increases in incident wave groupiness complement increases in $\bar{\bar{\Omega}}$ in driving a beach/surf-zone system to more dissipative states. The role of tide is less well defined. Table 3 shows that inclusion of $\bar{\bar{TR}}$ and particularly $\bar{\bar{GF}}$ into the analyses significantly increases predictability of the six beach states beyond that achieved by Wright et al.(1985a) on the basis of $\bar{\Omega}$ alone. Our new overall success rate of 36.2% (Table 3), while still fairly unimpressive, is a substantial improvement over the miserable 23.4% of Wright et al. (1985a)

Results of repeating the same type of analyses using the 1842-case time series with $\bar{\bar{GF}}$ excluded are presented in Tables 4a and b, 5 a, b, and c, and 6. Owing to the increase in n, the differences in tide range between states, though small, are seen to be highly significant. The reflective and "low-tide-terrace/ridge and runnel" states are associated with the highest tide ranges. However, even though tide range appears to play a significant role, the standardized canonical discriminant function coefficients presented in Table 5a indicate that $\bar{\bar{\Omega}}$ is ten times more important than $\bar{\bar{TR}}$ in contributing to function 1 which accounts for 98.2% of the variance. From Table 6 we may conclude that inclusion of the effects of tide range enhances predicibility significantly; however ignoring $\bar{\bar{GF}}$ significantly reduces the prediction success rate.

-- Results of Pair-wise Beach State Analyses --

The sequence of six beach states from the reflective to the dissipative extremes ordinally, but not linearly, expresses increasing "dissipativeness" or increasing relative breaker steepness. Hence, it is not very surprising that the discriminant functions obtained in the six-state analyses, while providing effective predictors of the extremes, lack the versatility to

discriminate reliably between the four intermediate states. Let us now pose three separate and simpler questions: (1) What factors determine whether an intermediate beach is likely to be in the "low-tide-terrace/ridge-and-runnel" (LTT) state or the "transverse-bar-and-rip" (TBR) state? (2) What factors determine whether an intermediate beach is likely to be in the "transverse-bar-and-rip" state or the "rhythmic-bar-and-beach" (RBB) state? (3) What factors determine whether an intermediate beach is likely to be in the "rhythmic-bar-and-beach" state or in the "longshore-bar-trough" (LBT)state?

The results of statistical analyses aimed at answering the above questions are embodied in Table 7. Highly significant roles are played by $\bar{\bar{\Omega}}$, $\overline{\overline{TR}}$, and $\overline{\overline{GF}}$ in distinguishing between the LTT and TBR states. Notably, in this case, incident wave groupiness ($\overline{\overline{GF}}$) dominates over $\bar{\bar{\Omega}}$. Higher values of both $\bar{\bar{\Omega}}$ and $\overline{\overline{GF}}$ favor the TBR state over the LTT state; however, the LTT state is favored by higher tide ranges as in the six state analyses.

Only $\bar{\bar{\Omega}}$ and $\overline{\overline{GF}}$ appear important in determining whether the beach state is TBR or RBB or LBT (Table 7). As in the six-state analyses presented in this paper as well as those presented by Wright et al.(1985a), increases in $\bar{\bar{\Omega}}$ drive the beach state through the sequence TBR→RBB→LBT and <u>vice versa</u>. Whether the beach state is "transverse-bar-and-rip" or "rhythmic-bar-and-beach" depends as strongly on the groupiness as it does on $\bar{\bar{\Omega}}$: higher $\overline{\overline{GF}}$ values favor RBB over TBR. A higher degree of groupiness also has a highly significant tendency to increase the likelihood of LBT occurring instead of RBB. However, $\bar{\bar{\Omega}}$ is stronly dominant over $\overline{\overline{GF}}$ as a source of the distinction between RBB and LBT.

Tide range turns out to be a non-significant factor in determining whether beach state is TBR, RBB, or LBT (Table 7). Pair-wise analyses repeated for $\bar{\bar{\Omega}}$ and $\overline{\overline{TR}}$ only but with 1842 cases confirm the results presented in Table 7: the differences in tide range between the LTT and TBR states are highly significant but the difference in $\overline{\overline{TR}}$ between the TBR and RBB states and between the RBB and LBT states are non-significant. Again, it must be emphasized that the tide range and its temporal variability on Narrabeen Beach are both small. Our observations elsewhere (e.g. Broome W.A., Wright et al.,1982) indicate that the TBR, RBB, and LBT are not present or are poorly developed in macrotidal environments.

Modes of Beach/Surf Zone Profile Behavior and Factors Affecting Them

-- Profile modes and their relationships to beach state --

Different modes of beach and surf zone profile configuration are expressed by "fixed-datum" and "floating-datum" eigenvectors. In the case of the Narrabeen Beach data set the "fixed-datum" vectors express little more than gross beach volume (Wright et al. 1985b). Hence subaerial beach volume conveys essentially the same information as the "fixed-datum" vectors and is a physically more meaningful quantity. Figure 5 shows a time series of changing subaerial beach volume expressed in m^3 per meter of beach width (for profile 3 in center of beach). These changes in beach volume can be considered to represent the simplest and most basic mode of profile behavior; this mode exhibits negligible correspondence to beach state and relates only weakly to profile shape (Wright et al. 1985b).

By using the time-varying shoreline position as the datum in the "floating-datum" eigenvector analyses, these vectors become indices of

profile shape alone. In order to establish the full range of possible profile modes, the principal components analysis was performed initially from nine separate profiles including one profile which is perennially reflective (Fisherman's Beach in the southern portion of the Narrabeen compartment) and one profile which is perennially dissipative (Seven Mile Beach; see description in Wright 1982). From these analyses, it was found that 98% of the variance in sand level over 9 profiles and 504 surveys was described by 5 floating-datum eigenvectors. Respectively, eigenvectors 1 through 5 account for 56.35%, 30.17%, 7.44%, 2.83% and 1.26% of the total variance in sand level.

Figure 6 illustrates the different profile characteristics expressed by the five important floating-datum eigenvectors. The solid curves in Figure 6 indicate the mean profile and the mode of departure from the mean profile is defined in terms of positive (+) versus negative (-) weightings on the different vectors. Table 8 indicates the relationships between each of the six beach states and the signs (+ , 0 or -) of the weightings on the five floating-datum eigenvectors. Time series of the weightings on the five vectors over a period of 2200 days (six years) are shown in Figure 7.

The first eigenvector conveys information as to the overall flattening (+ weighting) and steepening (- weighting) of the profile (Figure 6) and thus characterizes the degree of dissipativeness or reflectively of the surf zone and beach (Table 8). Vectors 2 and 3, in combination, express the extent of bar-trough relief. Although these two vectors appear very similar in form (Figure 6), they are in fact mutually orthogonal. The addition of positive weightings on both vectors 2 and 3 .ypifies highly accentuated bar trough topographies such as those described by Wright et al. (1986; e.g. LBT

and RBB; Table 8). Higher order features of the profiles such as bar asymmetries and the presence or absence of steps are expressed by the addition of vectors 4 and 5.

-- Profile responses to $\bar{\bar{\Omega}}$ and $\bar{\bar{TR}}$ --

Monthly subaerial beach volumes, monthly rates of volume change and the monthly weightings on each of the five floating datum eigenvectors were correlated with $\bar{\bar{\Omega}}$ and $\bar{\bar{TR}}$ using a simple linear correlation model. All correlation coefficients were too low (<0.4) to merit reporting. We should not expect much explanation of subaerial beach volume at all since that quantity expresses the time-integration of processes over prolonged periods of two or more years (e.g. Fig 5; Wright et al. 1985b). A more appropriate quantity is the rate of change of beach volume, $\Delta V/\Delta t$, where ΔV is the difference in beach volume any two successive surveys and Δt is the time interval (days) separating the surveys. We can use these data to examine the relative degree to which the erosional, accretionary or static response of the beach is related to $\bar{\bar{\Omega}}$ and $\bar{\bar{TR}}$. To do this, we simply identify three classes: (1) erosional in which $\Delta V/\Delta t<0$; (2) static in which $\Delta V/\Delta t=0$; and (3)accretionary in which $\Delta V/\Delta t>0$. ("Zero", in this grouping scheme, was defined as $0 \pm 0.1 m^3 \ day^{-1}$). In a similar manner, we grouped the weightings on the five floating datum eigenvectors into three classes : (1) negatively-weighted; (2) zero-weighted (i.e. near the mean); and (3) positively-weighted. ("Zero" in this case was defined as 0 ± 0.2). Performing discriminant analyses on data structured in this way made it possible for us to address the more straightforward questions of whether or not $\bar{\bar{\Omega}}$ and $\bar{\bar{TR}}$ exert any significant influences on the directionality of profile behavior.

No significant relationships were found for eigenvector 1 or 5. In the case of eigenvector 1 which primarily involves flattening or steepening of the surf zone, the dominant variations are long-term (>1yr) and are closely tied to the processes controlling slow exchanges of sediment between the shoreface and the surf zone. As indicated by Table 8, the sign of the weighting on Vector 5 reverses depending on whether the beach state is TBR or RBB; the distinction between these two beach states appears to be significantly influenced by $\overline{\overline{GF}}$ (table 7). The grouping factor, $\overline{\overline{GF}}$ was not included in the analyses of profile behavior because the $\overline{\overline{GF}}$ data cover a period which embraces only 20 surveys.

Significant associations between $\bar{\bar{\Omega}}$ and $\overline{\overline{TR}}$ and profile behavior were found for $\Delta V/\Delta t$ and eigenvectors 2,3 and 4. The direction of beach volume change (erosion or accretion) was found to be overwhelmingly dominated by $\bar{\bar{\Omega}}$ with $\overline{\overline{TR}}$ playing a weak secondary but statisically non-significant role. The usual and expected results emerged: large $\bar{\bar{\Omega}}$ values were associated with erosion.

The results of the discriminant analyses performed on the three discrete classes (-,0,+) of the weightings on vectors 2,3 and 4 are more interesting and are presented in Table 9. Probably the most important point to be drawn from Table 9 is that vectors 2 and 3, the two "bar-trough" functions are each dominated by different forcings. Eigenvector 2 tends to be positive (pronounced bar-trough) when tide range is lower and negative (subdued bar-trough topography or barless) when tide range is higher. Tide range ($\overline{\overline{TR}}$) is more than twice as important as $\bar{\bar{\Omega}}$ in contributing to discriminant function 1, which is the most important function (Table 9). In addition, the F ratios show that $\overline{\overline{TR}}$ differs significantly between the three

weighting classes (-,0, or +) while $\bar{\bar{\Omega}}$ does not. In contrast, eigenvector 3 seems to depend almost entirely upon $\bar{\bar{\Omega}}$: larger (but not extreme) values of $\bar{\bar{\Omega}}$ favor positive weightings on vector 3 and hence better developed bar-trough topography (the mean $\bar{\bar{\Omega}}$ values related to -,0, and + weightings on vector 3 are respectively 2.8, 3.3 and 3.5). Tide range also has a relatively unimportant effect on vector 4; the role of $\bar{\bar{\Omega}}$ is significant but not highly significant. The effect of $\bar{\bar{\Omega}}$ on vector 4 parallels that described for vector 3: larger values are associated with positive weightings.

Discussion and Conclusions

We had hoped, originally, to obtain a set of empirical equations for predicting the time-varying state and profile configuration of a beach and surf zone in terms of $\bar{\bar{\Omega}}$, $\bar{\bar{TR}}$, and $\bar{\bar{GF}}$. In fact, the necessary coefficients for "predictions" are embodied in the foregoing statistical results; however, we refrain from offering a predictive "recipe" because such a scheme based on our data would be unreliable and not universal. The associations we found are, in many cases, highly significant, but they are not direct and specific enough to permit quantitative predictions to be made within prescribed error limits. There are several reasons for the limitations to our success: (1) The paramount shortcoming of our approach has been our neglect of the shoreface and inner shelf. Subsequent investigators must extend their surveys well beyond the surf zone at least to the depth of "closure" as is presently done by personnel at the Corps of Engineers Field Research Facility at Duck, N.C. (e.g. Birkemeier 1985; Mason et al. 1985). (2) Monthly resurveying is far too infrequent to permit causal associations to be identified between rapidly changing waves and

beach conditions. Surveys at daily or shorter intervals including surveys during high-energy events, are needed and are now obtainable by means of surf zone sleds such as that used by Sallenger et al. (1983, 1985). It seems unlikely that significant new insights into nearshore morphodynamic processes will be gained from further "conventional" infrequent (order monthly) surveys of the beach and surf zone. (3) The true roles of temporal variations in tide range are probably poorly elucidated by the Narrabeen data set since neither the mean tide range nor the neap-to-spring range are very large at that site. What is needed is a comparable time series from a relatively energetic beach in a mesotidal environment where the neap-to-spring variation is large.

Predictions as to whether a beach is likely to be dissipative, intermediate, or reflective remain relatively straightforward involving, primarily, $\bar{\bar{\Omega}}$ as concluded by Wright and Short (1984) and Wright et al. (1985a). Furthermore, disequilibrium concepts can be applied to estimate the most likely direction of short-term change (i.e. eroding to become more dissipative or accreting to become more reflective) of a beach as a function of both preexisting state and Ω using Figure 9 of Wright et al. (1985a), a modified version of which is shown in Figure 8. However, as Wright et al. (1985a) pointed out, their "dynamic" predictive approach only works well when any particular combination of immediately-antecedent beach state and prevailing Ω is such as to place the beach outside of a swath of relative stability which straddles the equilibrium curve (Fig. 8). The width of the "stable" region typically embraces two intermediate states for any particular Ω value within the intermediate range ($2<\Omega<6$; Fig.8). For cases which are within the "stable" band-which is where most of the Narrabeen data

lie for most of the time-predicting the direction of change of beach state in terms of Ω alone is a relatively ambiguous process. In an attempt to reduce this ambiguity, we have addressed, in this paper, the question of how $\overline{\overline{TR}}$ and $\overline{\overline{GF}}$ may act in concert with Ω to determine beach state and profile configuration. Figure 8 indicates, albeit qualitatively, how the effects of $\overline{\overline{TR}}$ and $\overline{\overline{GF}}$, superimposed on the effects of Ω (or $\bar{\Omega}$) and antecedent state, may determine beach state. More explicity, we can summarize our conclusions as to the roles of $\overline{\overline{TR}}$ and $\overline{\overline{GF}}$ as follows:

-- The role of temporal variations in tidal range --

Neap-to-spring, and longer term, variations in tide range modulate surf zone processes by causing temporal variations in surf zone width and breaker position. We see from our analyses that these modulations produce morphologic consequences in terms of both beach state and profile shape. The significant effect of $\overline{\overline{TR}}$ on beach state applies principally to intermediate states at the reflective end of the sequence (LTT, TBR). <u>Provided</u> that the $\bar{\bar{\Omega}}$ value lies within the appropriate range ($2.0<\bar{\bar{\Omega}}<3.5$) to favor either the LTT state <u>or</u> the TBR state, then spring tides (or higher tidal ranges) will enhance the probability that the low-tide terrace/ridge and runnel state will prevail (Fig.8). With regard to profile configuration, higher tidal ranges tend to mitigate against highly accentuated bar-trough topography. Again, provided that wave conditions ($\bar{\Omega}$) are right to permit one of the bar-trough states, the most accentuated topography will exist when tidal range is at its minimum.

-The role of temporal variations in incident wave groupiness-

The apparent causal roles of incident wave groupiness <u>that we observe</u> are probably mainly attributable to the fact that higher $\overline{\overline{GF}}$ values imply

more energetic surf for any given $\bar{\bar{\Omega}}$ value. This is particularly suggested by the highly significant tendency for progressively higher $\overline{\overline{GF}}$ values to be accompanied by progressively more dissipative beach states when the $\bar{\bar{\Omega}}$ requirements are also met. The measureable dominance of higher $\overline{\overline{GF}}$ values in causing the TBR beach state to replace the LTT state (Fig. 8) may reflect stronger forcing of attendant infragravity waves by the more groupy waves in addition to the associated higher breaker height and work rate. A similar argument may explain the fact that the RBB state is distinguished from the TBR state principally on the basis of $\overline{\overline{GF}}$ and secondarily on the basis of $\bar{\bar{\Omega}}$ (Fig.8).

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LIST OF TABLES

TABLE 1a. AVERAGE ASSOCIATIONS BETWEEN

BEACH STATE, $\overline{\overline{\Omega}}$, $\overline{\overline{TR}}$, AND $\overline{\overline{GF}}$ FOR NARRABEEN BEACH

Beach State	n	Mean $\overline{\overline{\Omega}}$	Mean $\overline{\overline{TR}}$	Mean $\overline{\overline{GF}}$	Standard Deviation $\overline{\overline{\Omega}}$	Standard Deviation $\overline{\overline{TR}}$	Standard Deviation $\overline{\overline{GF}}$
Reflective	7	2.16	1.16	0.28	0.73	0.07	0.01
LTT	59	2.59	1.18	0.28	0.53	0.19	0.03
TBR	189	3.05	1.10	0.31	0.81	0.20	0.04
RBB	223	3.44	1.13	0.33	0.84	0.19	0.04
LBT	101	4.81	1.15	0.35	1.29	0.21	0.04
Dissipative	7	5.50	1.10	0.35	1.40	0.09	0.03
Overall	586	3.48	1.13	0.32	1.15	0.19	0.04

TABLE 1b. UNIVARIATE F RATIOS

AND SIGNIFICANCE LEVELS FOR GROUP MEANS

Variable	F	Significance
$\overline{\overline{\Omega}}$	73.41	0.000
$\overline{\overline{TR}}$	2.04	0.072 (NS)
$\overline{\overline{GF}}$	32.55	0.000

TABLE 2a. DISCRIMINANT ANALYSIS RESULTS FOR SIX BEACH STATES

Function	Eigen-value	% Explained Variance	Canonical Correlation	SCDFC $\overline{\overline{\Omega}}$	SCDFC $\overline{\overline{TR}}$	SCDFC $\overline{\overline{GF}}$	UCDFC $\overline{\overline{\Omega}}$	UCDFC $\overline{\overline{TR}}$	UCDFC $\overline{\overline{GF}}$	UCDFC Constant
1	0.820	92.99	0.67	0.84	-0.09	0.49	0.92	-0.47	13.68	-7.06
2	0.051	5.79	0.22	0.51	0.43	-0.80	0.55	2.25	-22.35	2.68
3	0.011	1.21	0.10	-0.24	0.90	0.35	-0.26	4.68	9.79	-7.50

Function = canonical discriminant functions.

SCDFC = standardized canonical discriminant function coefficients which indicate the relative importance of the variables $\overline{\overline{\Omega}}$, $\overline{\overline{TR}}$, and $\overline{\overline{GF}}$ to the three functions.

UCDFC = unstandardized canonical discriminant function coefficients.

TABLE 2b. Chi SQUARED AND SIGNIFICANCE

LEVELS FOR THE DISCRIMINANT FUNCTIONS

Functions	χ^2	d.f.	Significance
1+2+3	382.7	15	0.000
2+3	35.1	8	0.000
3	6.2	3	0.103 (ns)

TABLE 2c. BEACH STATE

DISCRIMINANT SCORES AT GROUP CENTROIDS

Beach State	Function 1 Scores	Function 2 Scores	Function 3 Scores
Reflective	-1.78	0.25	0.12
LTT	-1.38	0.50	0.09
TBR	-0.52	-0.07	-0.12
RBB	0.07	-0.19	0.09
LBT	1.58	0.21	0.01
Dissipative	2.29	0.40	-0.38

TABLE 3. PREDICTED VERSUS ACTUAL BEACH STATE;

PERCENTAGES OF CORRESPONDENCE ($\bar{\bar{\Omega}}$, $\overline{\overline{TR}}$, $\overline{\overline{GF}}$)

Actual State	Predicted State: Reflective	LTT	TBR	RBB	LBT	Dissipative
Reflective	71.4	14.3	14.3	0.0	0.0	0.0
LTT	20.3	54.2	18.6	6.8	0.0	0.0
TBR	13.8	19.6	31.7	28.0	5.8	1.1
RBB	6.7	7.2	26.9	36.8	17.5	4.9
LBT	0.0	4.0	3.0	26.7	27.7	38.6
Dissipative	0.0	0.0	0.0	14.3	14.3	71.4

Percentage of cases classified correctly: 36.2% (n = 586).

TABLE 4a. AVERAGE ASSOCIATIONS BETWEEN

BEACH STATE, $\bar{\bar{\Omega}}$, AND $\overline{\overline{TR}}$ FOR NARRABEEN BEACH (1842 CASES)

Beach State	n	Mean $\bar{\bar{\Omega}}$	Mean $\overline{\overline{TR}}$	Standard Deviation $\bar{\bar{\Omega}}$	Standard Deviation $\overline{\overline{TR}}$
Reflective	62	2.29	1.18	0.45	0.15
LTT	293	2.69	1.14	0.61	0.19
TBR	830	3.26	1.11	0.72	0.19
RBB	467	3.63	1.10	0.79	0.19
LBT	179	4.72	1.13	1.26	0.20
Dissipative	11	5.76	1.10	1.21	0.10
Overall	1842	3.39	1.12	0.99	0.19

TABLE 4b. UNIVARIATE F RATIOS

AND SIGNIFICANCE LEVELS FOR GROUP MEANS

Variable	F	Significance
$\bar{\bar{\Omega}}$	209.6	0.0
$\overline{\overline{TR}}$	4.62	0.001

TABLE 5A. DISCRIMINANT ANALYSIS RESULTS

FOR SIX BEACH STATES BASED ON $\overline{\overline{\Omega}}$ AND $\overline{\overline{TR}}$

Function	*Eigenvalue*	% Explained *Variance*	Canonical *Correlation*	SCDFC $\overline{\overline{\Omega}}$	SCDFC $\overline{\overline{TR}}$	UCDFC $\overline{\overline{\Omega}}$	UCDFC $\overline{\overline{TR}}$	UCDFC Constant
1	0.58	98.20	0.61	1.00	-0.10	1.27	-0.51	-3.73
2	0.01	1.80	0.10	0.06	1.00	0.08	5.24	-6.11

Function = canonical discriminant functions.

SCDFC = standardized canonical discriminant function coefficients which indicate the relative importance of the variables $\overline{\overline{\Omega}}$ and $\overline{\overline{TR}}$ to the two functions.

UCDFC = unstandardized canonical discriminant coefficients.

TABLE 5B. Chi SQUARED AND

SIGNIFICANCE LEVELS FOR THE DISCRIMINANT FUNCTIONS

Functions	χ^2	d.f	Significance
1+2	855.0	10	0.000
2	19.3	4	0.000

TABLE 5C. BEACH STATE DISCRIMINANT

SCORES AT GROUP CENTROIDS

Beach State	Function 1 Scores	Function 2 Scores
Reflective	-1.49	0.26
LTT	-0.90	0.12
TBR	-0.16	-0.06
RBB	0.33	-0.07
LBT	1.69	0.18
Dissipative	3.03	0.10

TABLE 6. PREDICTED VERSUS ACTUAL BEACH STATE;

PERCENTAGES OF CORRESPONDENCE ($\overline{\overline{\Omega}}$, $\overline{\overline{TR}}$)

	Predicted State					
Actual State	Reflective	LTT	TBR	RBB	LBT	Dissipative
Reflective	64.5	32.3	1.6	1.6	0.0	0.0
LTT	33.8	35.5	22.2	6.1	2.0	0.3
TBR	11.6	22.9	27.1	28.4	9.4	0.6
RBB	4.9	18.5	24.2	34.0	19.9	3.4
LBT	0.6	5.6	8.4	25.1	28.5	31.8
Dissipative	0.0	0.0	0.0	18.2	9.1	72.7

Percentage of case predicted correctly: 31.9% (n = 1842).

TABLE 7. DISCRIMINANT ANALYSIS

RESULTS FOR BEACH STATE PAIRS

	LTT vs. TBR	TBR vs. RBB	RBB vs. LBT
n	255	412	324
F ($\overline{\overline{\Omega}}$)	21.92 (0.000)	22.58 (0.000)	130.70 (0.000)
F ($\overline{\overline{TR}}$)	8.19 (0.005)	2.49 (ns)	0.80 (ns)
F ($\overline{\overline{GF}}$)	35.99 (0.000)	23.06 (0.000)	17.37 (0.000)
Eigenvalue	0.278	0.103	0.429
Canonical Correlation	0.467	0.306	0.548
SCDFC $\overline{\overline{\Omega}}$	0.639	0.661	0.943
SCDFC $\overline{\overline{TR}}$	-0.454	0.086	0.041
SCDFC $\overline{\overline{GF}}$	0.684	0.671	0.224
UCDFC $\overline{\overline{\Omega}}$	0.850	0.801	0.942
UCDFC $\overline{\overline{TR}}$	-2.352	0.449	0.211
UCDFC $\overline{\overline{GF}}$	20.06	17.9	5.975
UCDFC (Constant)	-5.920	-8.86	-5.875
χ^2	61.77 (0.000)	40.07 (0.000)	114.45 (0.000)
Discriminant Score 1	-0.889	-0.348	-0.440
Discriminant Score 2	0.311	0.295	0.970
Total Predictability	69.0%	60.9%	75.3%

F ( ) = F-ratio for variable indicated in parentheses.
Discriminant Score = canonical discriminant score for centroids of the two groups in each pair. The number designates the group in the pair. For example in the LTT vs. TBR column, Discriminant Score 1 is the score for the LTT state while Discriminant Score 2 is the score for the TBR state.

Table 8. Relationships Between Beach State and the Signs of *Weightings* on the Five Floating Datum Eigenvectors.

Floating Datum Eigenvector No.	Beach State Refl.	LTT	TBR	RBB	LBT	Diss.
E1	-- *	-	~0	~0	-	++ *
E2	-	-	+	+	+	-
E3	-	-	~0	+	+	+
E4	+	~0	~0	-	+	~0
E5	+	+	+	-	~0	-

*Extreme negative and extreme positive weightings are indicated by -- and ++ respectively.

TABLE 9. ANALYSIS OF VARIANCE AND DISCRIMINANT ANALYSIS RESULTS FOR $\bar{\bar{\Omega}}$ AND $\overline{\overline{TR}}$ IN RELATION TO THE SIGNS OF FLOATING DATUM EIGENVECTOR WEIGHTINGS

	Eigenvector 2 - vs. 0 vs. +	Eigenvector 3 - vs. 0 vs. +	Eigenvector 4 - vs. 0 vs. +
n	70	70	70
F ($\bar{\bar{\Omega}}$)	1.07 (ns)	6.30 (0.003)	3.74 (0.029)
F ($\overline{\overline{TR}}$)	4.46 (0.015)	0.38 (ns)	1.23 (ns)
Eigenvalue (f1)	0.163	0.201	0.114
Eigenvalue (f2)	0.010	0.003	0.034
Canonical Correlation (f1)	0.374	0.409	0.320
Canonical Correlation (f2)	0.098	0.055	0.182
% Variance (f1)	94.43	98.48	76.86
% Variance (f2)	5.57	1.52	23.14
SCDFC $\bar{\bar{\Omega}}$ (f1)	-0.444	0.980	0.985
SCDFC $\overline{\overline{TR}}$ (f1)	0.927	-0.261	0.167
SCDFC $\bar{\bar{\Omega}}$ (f2)	0.899	0.206	-0.170
SCDFC $\overline{\overline{TR}}$ (f2)	0.381	0.967	0.986
χ^2 (f1)	10.68 (0.030)	12.41 (0.015)	9.42 (0.051)
χ^2 (f2)	0.64 (ns)	0.21 (ns)	2.244 (ns)

- or + indicate negative or positive weighting on eigenvectors.

0 indicates that the weighting was close to zero (mean) defined for practical purposes by values between -0.2 and +0.2.

FIGURE CAPTIONS

FIGURE 1. The relationship between the grouping factor, GF, and sea-surface (η) time series of a hypothetic "perfectly" grouped wave train with GF = 1 (upper curve) and two natural wave time series with GF = 0.58 and 0.38. The large displacement curves are the actual wave time series; the smoother low amplitude curves represent the time series of g_t.

FIGURE 2. Predicted daily variations in tide range, TR, weighted tide range $\overline{\overline{TR}}$ and the corresponding daily mean sea level (the smoother, lower amplitude curve) for 1977.

FIGURE 3. Time series of daily beach state and daily Ω, $\overline{\overline{\Omega}}$, $\sqrt{2}\,\sigma_g$, GF, and tide range, TR for Narrabeen Beach indicating the type of data used for the statistical analyses. (The actual period covered by the series shown is 1 January 1977 to September 1978.)

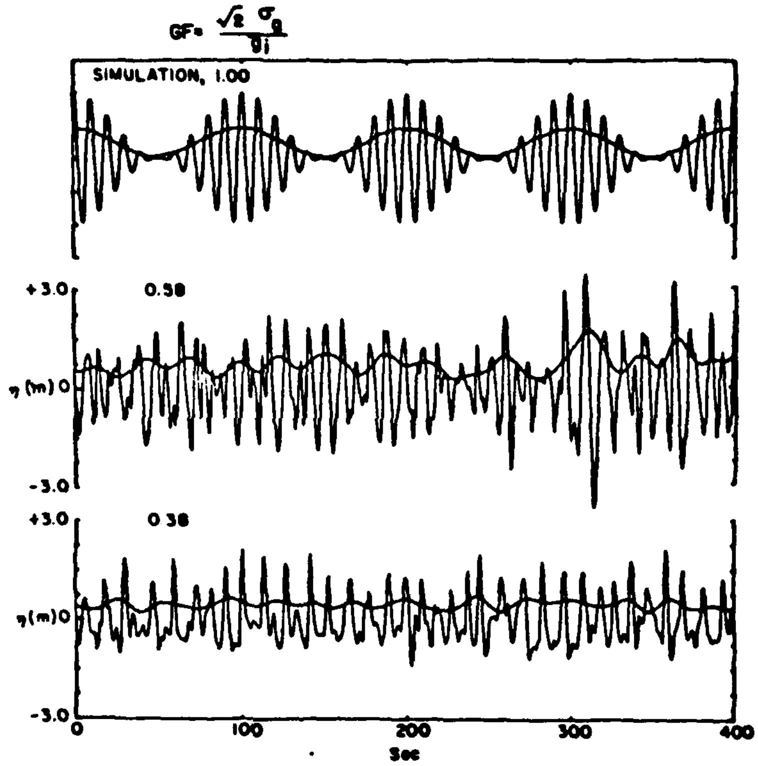
FIGURE 4. Beach state in relation to $\overline{\overline{\Omega}}$ and $\overline{\overline{TR}}$ (A) and $\overline{\overline{\Omega}}$ and $\overline{\overline{GF}}$ (B). The centers of the crosses indicate the mean values of the corresponding forcing parameters ($\overline{\overline{\Omega}}$, $\overline{\overline{TR}}$, $\overline{\overline{GF}}$) and bars embrace ± one standard deviation.

FIGURE 5. Time series of subaerial beach volume (in m^3 per meter of beach width) for profile 3 in the fully exposed center of Narrabeen Beach based on monthly levelling transects.

FIGURE 6. The five floating datum modes of beach and surf zone profile variation. The mean profile is indicated by the solid curve. Positive and negative weightings on each vector are indicated respectively by the dashed and dotted curves. The actual profile as it appears at any given time expresses the addition of the different modes of profile shape.

FIGURE 7. Time series of the monthly weightings on each of the five floating datum eigenvectors for profile 3 in the center of Narrabeen Beach.

FIGURE 8. Directions of beach state change as determined by antecedent beach state, Ω, TR, and GF. The effects of TR and GF are mainly exerted when the beach is in the "stable" region with respect to prevailing beach state and Ω combinations. The dashed arrows indicate the effects of increased tide range on beach state. The solid arrows indicate the effects of increased groupiness on beach state; in this case relative variations in the importance or strength of the effect are shown by varying arrow thicknesses with the thickest arrow designating the strongest effect.



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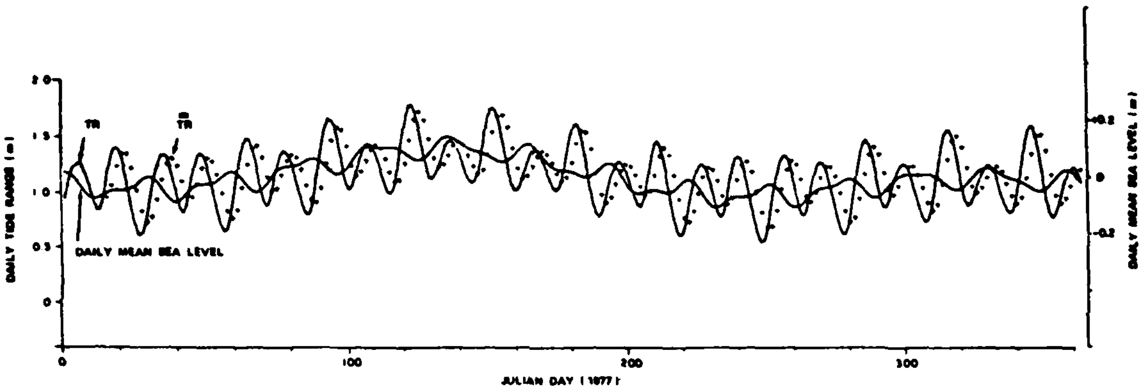

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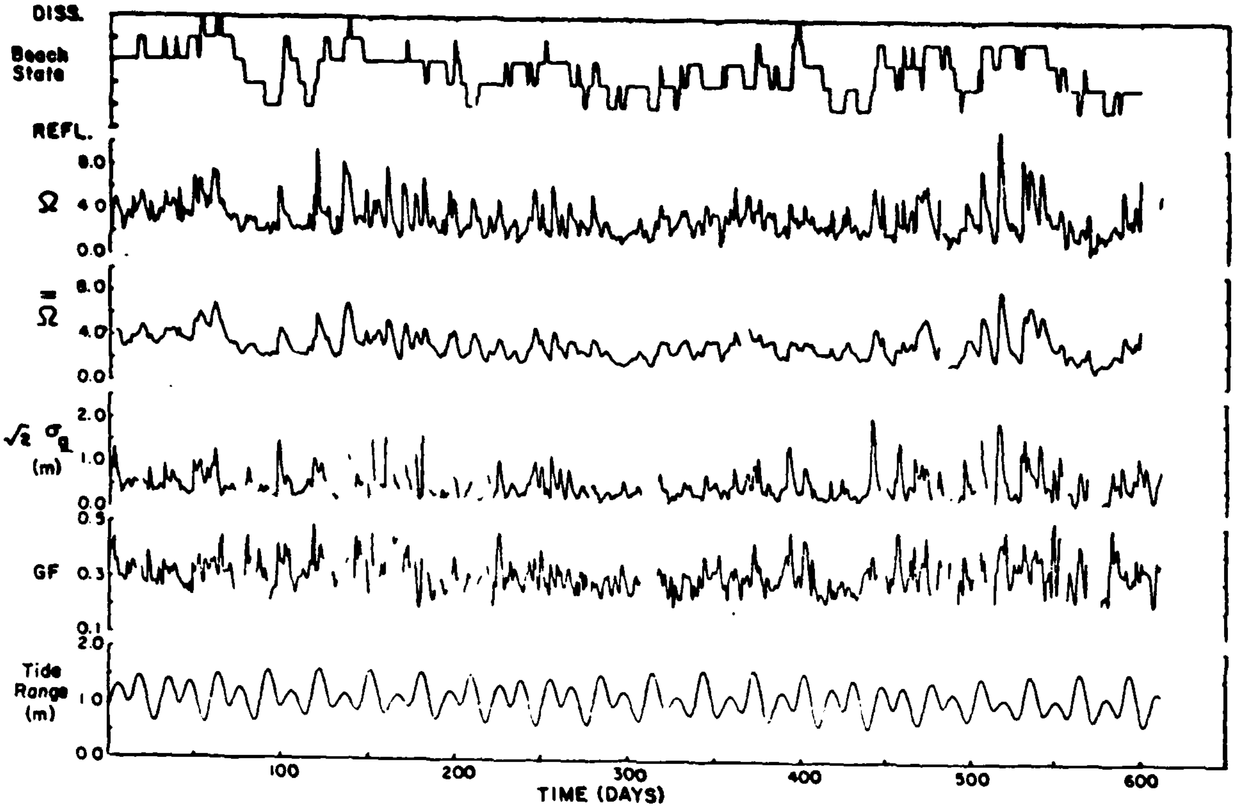

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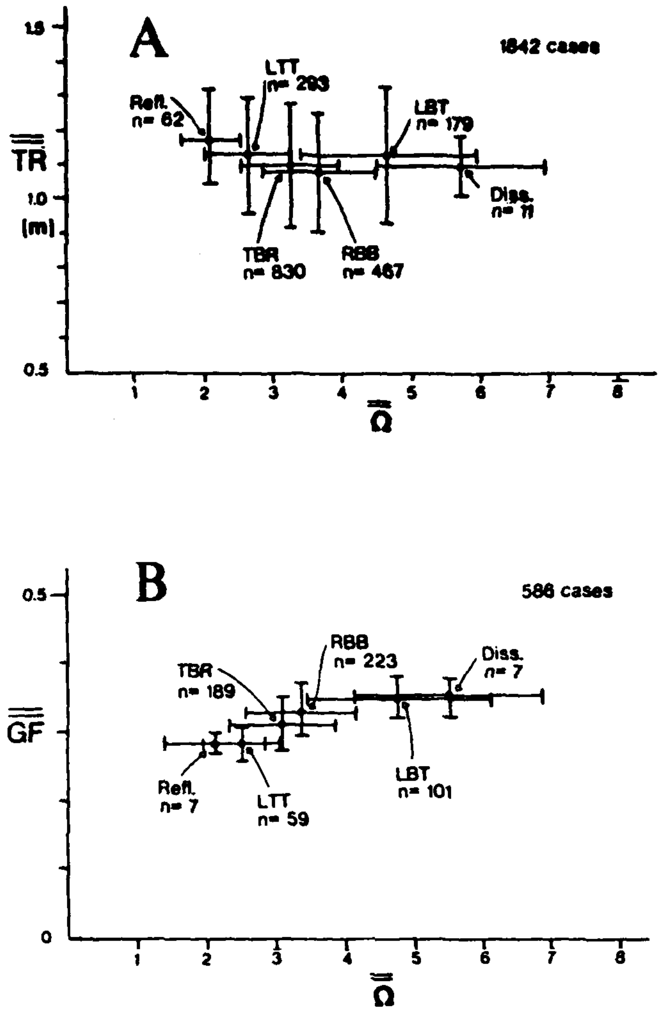

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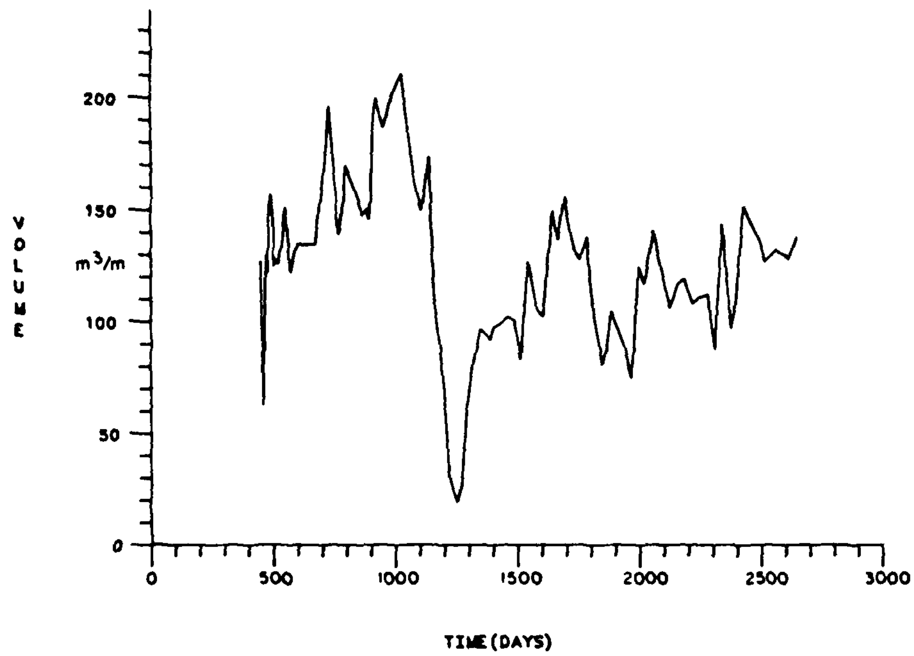

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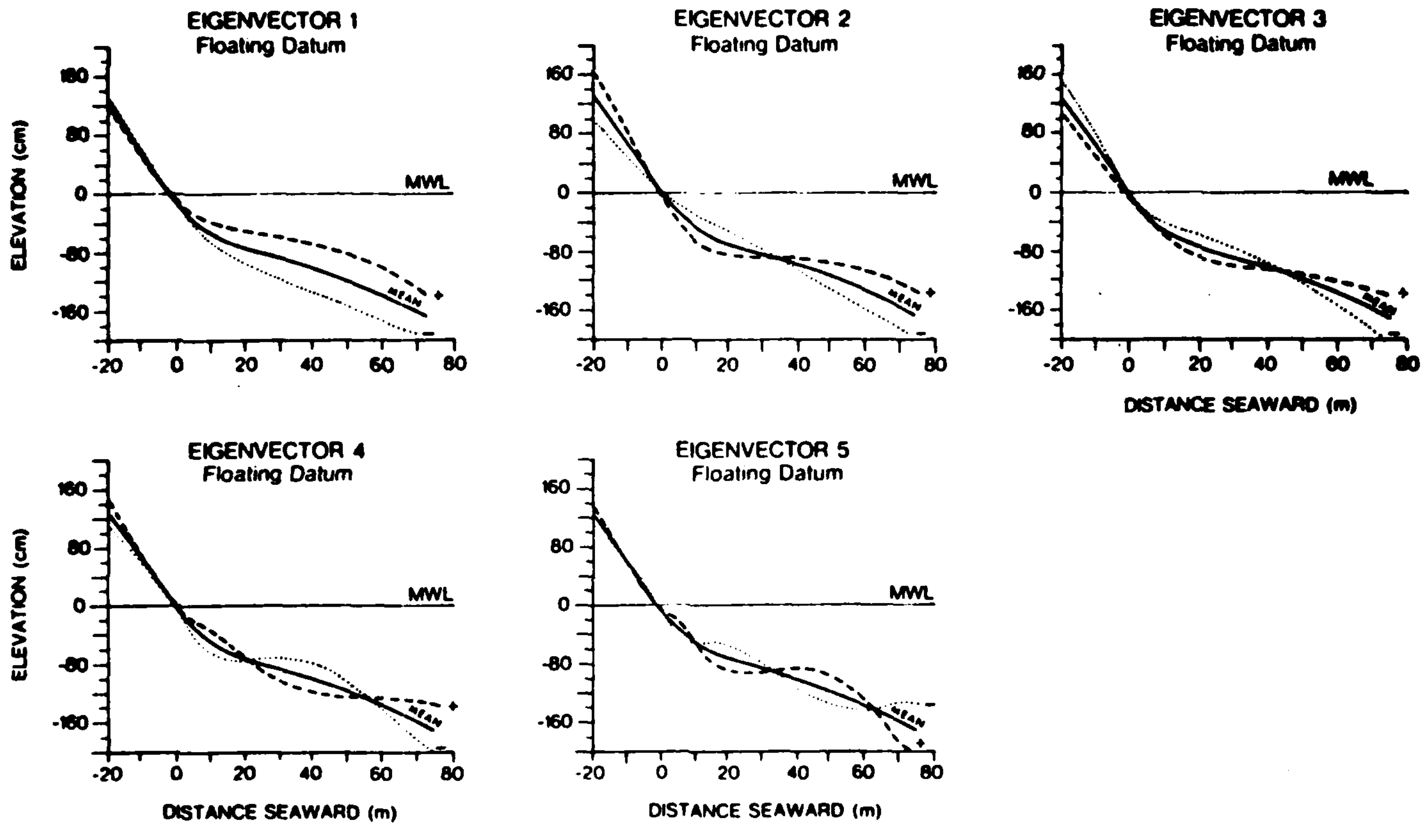

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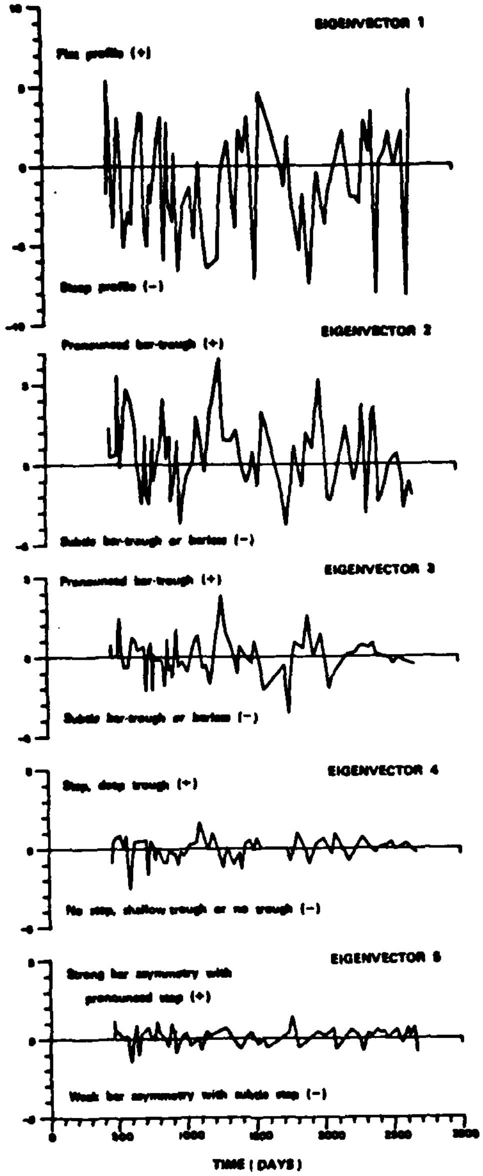

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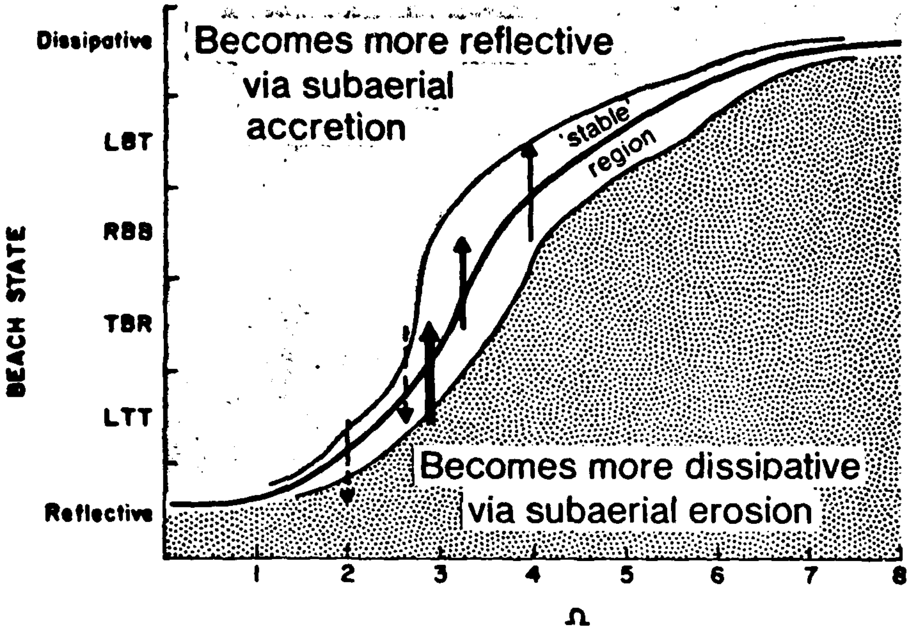

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